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# EXPERIMENTAL INVESTIGATIONS OF PIEZOELECTRIC ENERGY HARVESTING WITH TURBULENT FLOW

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***ABSTRACT***

***Agreeing to the Piezoelectric Energy Harvesting Forecast by IDTechEx, the development of the piezoelectric industry is reckoned from $145 million in 2018 to $667 million in 2022. This clearly indicates the escalation of interest of the renewable energy market in piezoelectric since its discovery in 1880. Inspired by the growing demand and unique ability of a piezoelectric energy to convert mechanical energy into electrical energy, the authors present an efficient model of a piezoelectric energy harvester in this technical paper. The proposed harvester is capable of producing electricity by converting dynamic fluid flow pressure of waste water into electrical energy using piezoelectric patches made from PZT (Lead Zirconate Titanate). The patches are attached inside the pipes via a mesh and utilizes the flow of segregated waste water flow from households, factories, etc. to produce feasible electricity to power small scale electronic devices. The authors have established the feasibility studies, system engineering experimentations and gathered experimental results confirming the idea and motivation to fabricate and test the actual product.***

***KEYWORDS: Energy Harvesting, Fluid Flow, Maximum Power, Piezoelectric Energy, Piezoelectric Energy Harvester, & Voltage Generated***

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Original Article

## INTRODUCTION

Energy harvesting or energy scavenging is a process of utilizing the available unused or untapped energy from the environment, conditioning it in a convenient manner and store it for future use [1]. This energy can be stored as electrical energy (the most used forms of energy) which is usable for multiple applications. A possible source of energy harvesting can be the untapped dynamic force of a flowing fluid. Researchers are being carried out in the same field by utilizing with different means, materials and structures [2-4]. The authors investigated numerous studies and found out that the most viable means for harvesting energy to create a self- powering device from fluid flow is by using piezoelectric materials [5-6].

Piezoelectric materials have a vast domain of such applications, although its low power generation capacity and storage issue restricts its usage. Although most researches have widely been carried out to convert mechanical vibrations into electricity by using piezoelectric energy harvesters [7-13], there is a lot of scope in utilizing flowing fluid as a potential energy source. Piezoelectric materials are favoured, because the power requirement for initiation is very low as compared to other available options and they are easy to integrate with other systems. In addition, these devices can provide us with an alternative energy solution that can dramatically

change the way we harvest alternative form of energy from the ambient without producing any carbon footprint at all.

The main aim of this work is to provide a renewable micro energy source that can power portable devices. The authors seek to achieve this by developing a model of the piezoelectric energy harvester, which can convert the dynamic fluid flow pressure of water into electrical power using different configuration of circuits containing piezoelectric patches made up of ceramic called PZT (Lead Zirconate Titanate). The authors, hence, analyze the voltage developed under these different parameters from the circuits and compare the results obtained.

## PERSPECTIVE SYSTEM

The study of this research is characterized and segmented into the following basics steps. The investigation provides us with an overview of the research performed by the authors. The basic steps of the working are shown in the Figure. 1. The energy produced from the harvester have been provided with a source of fluid flow, in this case, running water that creates the dynamic and fluid pressure for the piezoelectric material to convert this pressure into electrical energy [14-22]. The generated voltage can be utilized or stored in a number of applications. The generated piezoelectricity from the material is in the form of an AC output, which can be converted into DC output by using rectifier circuit along with capacitors or batteries are used for storing purposes.

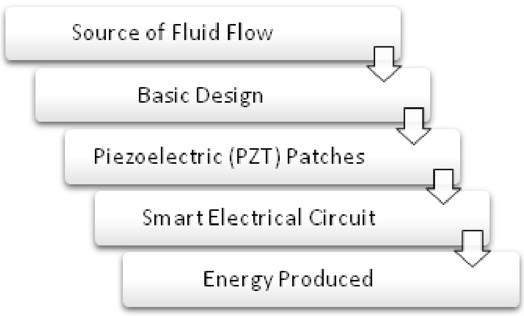



**Figure 1: Steps Involved in Energy Harvesting**

## MATERIAL SELECTIONS

In the present study, PZT (Lead Zirconate Titanate) was used for harvesting the energy from the dynamic flow of water. PZT is a metallic-oxide based ceramic piezoelectric material. It exhibits a greater sensitivity as compared to its predecessor i.e. Barium Titanate. Figure 2 shows the picture of the piezoelectric patch made up of PZT that was used for energy harvesting in this case study. It is physically strong and flexible, which enables it to function against high pressure and forces when applied to it by flowing water. Attributes such as chemical inertness and wide reach of possible variations makes PZT suitable for the piezoelectric harvester.

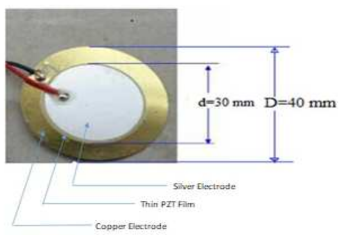



**Figure 2: PZT Piezo-Patch**

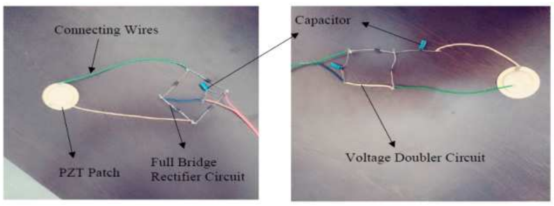
Table 1 shows the basic properties of the PZT piezo-patch used for energy production.

**Table 1: Properties of PZT Material**

| Property | Value | Units |
|---|---|---|
| Compound Formula | $O_5PbTiZr$ | - |
| Molecular Weight | 426.49 | g/mol |
| Density | 7.75-8.0 | kg/m$^3$ |
| Young's Modulus | 49 | GPa |
| Curie Temperature | 360 | deg. C |
| Dielectric Constant | 1700 | - |
| Coupling Coefficient ($k_{33}$) | 0.69 | $K^2$ |
| Dielectric Strength | 8-16 | MV/m |
| Strain Coefficient ($d_{33}$) | 3.6e-10 | m/V |
| Voltage Coefficient ($d_{33}$) | 0.025 | V*m/N |
| Thermal Expansion Coefficient | 11e-6 | /K |

## DESCRIPTION OF SMART ELECTRICAL CIRCUIT

The piezoelectric patch circuit produces output in AC (alternating current) which can be converted into DC (direct current) voltage by using Full-bridge rectifiers and Voltage doubler circuits. Capacitors have been employed in the study to store the extracted energy that can be used for further applications. The following Figure. 3 depicts the piezoelectric patch connected to two different circuits and used for energy production for this investigation.

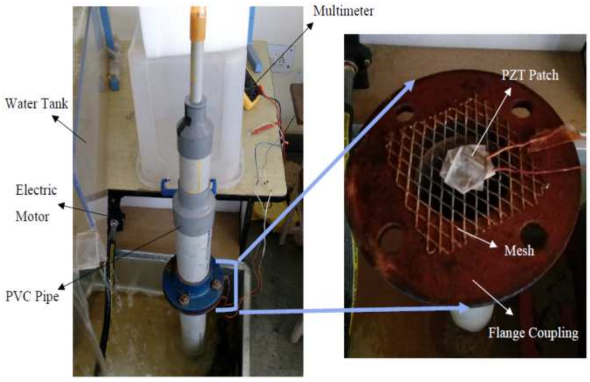



**(a)** **(b)**

**Figure 3 (a): PZT Patch with Full Bridge Rectifier Circuit**
**(b): PZT Patch with Voltage Doubler Circuit**

## MODEL OF THE ENERGY HARVESTING SYSTEM

The proposed mechanical model is made from a PVC (Polyvinyl Chloride) pipe which is cut from the middle. The portions of the pipe are connected by a flange bearing and tightened by the means of bolts and nuts. Inside the flange coupling is two meshes used to provide housing to the piezoelectric patches. These patches are further connected to the circuit. The patches are covered in tape to increase their durability while the flowing water strikes at its surface to release electrical voltage. This voltage is measured by using a multimeter attached to the end of the rectifier circuit. The mannequin has been tested for rectifier circuit and voltage doubler circuit. This energy harvesting model can be used where the water supply is continuous, ranging from low flow discharge as in a household kitchen drains, brook, etc. to high flow water discharge sources such as rivers, lakes, bridges, waterfall, industrial waste disposal etc. Figure. 4 depicts the working model details.




**(a) (b)**

**Figure 4 (a): Working Model of the Energy Harvester**
**(b) Housing of Piezoelectric Patches inside the Flange Coupling**

A water tank is used to store and supply the water to the system. An electric motor is used to recirculate the flow of water. The flow is measured using the water flow measuring system. It consists of a bypass control valve and a flow control valve to keep the required flow of water measurement in check. Figure. 5 shows the water flow measuring system that was used in the experiment to control the rate of fluid flow and to measure its rate.


**Figure 5: Water Flow Measuring System**

## RESULTS AND DISCUSSIONS

The smart circuit is used for single and double patches to get the corresponding voltage produced by using a multi-meter. Data obtained from the experiment is recorded and compared for the patches. Figure 6 shows the flow diagram of the analysis of the circuits.

| | | |
|---|---|---|
| Circuits | Full Bridge Rectifier | Single Piezo Circuit |
| | | Double Piezo Circuit |
| | Voltage Doubler | Single Piezo Circuit |
| | | Double Piezo Circuit |

**Figure 6: Hybrid of Analytical Study for the Circuits**

An output voltage is generated by single and double PZT patches and were tested by using dynamic pressure of water. The voltage produced from the patches are measured at different flow rates of flowing water and the results for the full bridge rectifier and voltage doubler circuit systems are summarized and compared in Figure. 7 and Figure. 8. It is observed that the optimum flow rate for single piezo patch is 20-23 litres/min and double piezo patch, in a parallel connection, is 30-32 litres/min. With an increase in the rate of flowing water, the voltage output rises considerably in all the cases. Also, the output voltage for both patches is greater for the voltage doubler circuit.

The comparison between the output voltages for the two patches have been presented in Figure. 9 and Figure. 10. It is noted that the produced voltage output of the double piezo patch is more than that of single piezo for a full bridge rectifier circuit. The voltage production is relative to the speed of the water striking i.e. with increase in velocity of coming

water, the voltage production increases. PZT patch circuit with single piezo can provide maximum voltage of 3.348 V at an optimal flow speed of 20.250 litre/min whereas in the case of double piezo patches, the maximum voltage produced is 2.420 V at 31.266 litre/min. It should also be noted that there is a special case for the flow speed of 20-21 litre/min in the full bridge rectifier circuit wherein it is beneficial to deploy a single piezo patch since it is capable of providing more voltage than the double piezo patch in parallel connection circuit.

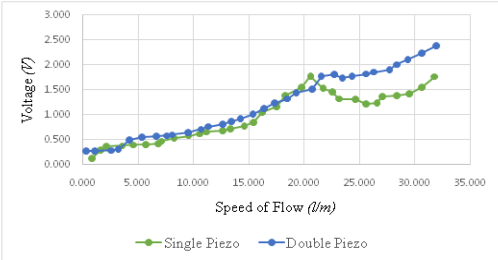



**Figure 7: Comparison of Voltage Generated by PZT Using Single and Double Patches for Full Bridge Rectifier Circuit**

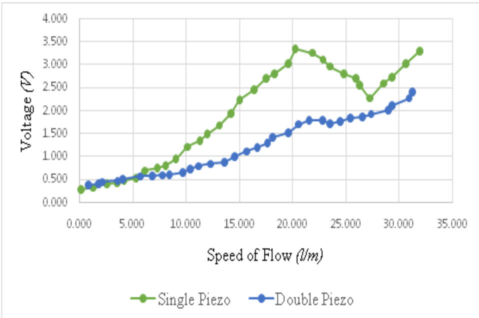



**Figure 8: Comparison of Voltage Generated by PZT Using Single and Double Patches for Voltage Doubler Circuit**

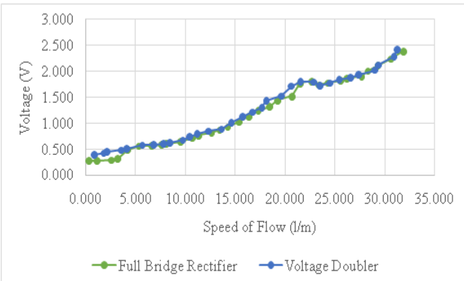



**Figure 9: Comparison of Voltage Generated by PZT Using Single Piezo Patch**

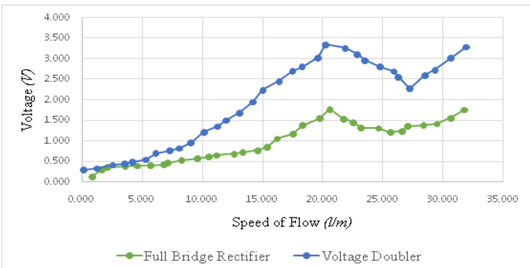



**Figure10: Comparison of Voltage Generated by PZT Using Double Piezo Patch (Parallel Connection)**

## CONCLUSIONS

The authors present a feasible and a potential source of renewable energy that can help us reduce the dependence on non renewable energy sources such as batteries made up of harmful chemicals such as lead, lithium, cadmium and mercury. The piezoelectric energy harvester, discussed in the paper, can provide a wide range of future applications, some of which are elaborated further. As, the piezoelectric energy harvester uses the dynamic motion of flowing fluid to produce output voltage, it can be utilized to mimic biomimetic motion, such as the motion of a fish, jellyfish, eel, etc. to build a robotic underwater device to provide constant electrical energy. This system can be incorporated at the end of the flaps of water transport means such as motorboats, ships, etc. to provide electric energy to power small electrical devices. Power can be generated from flowing water, which can also be the water waste from households, industries, power plants etc. A hybrid grid structure can utilize the presented harvester in a flowing water canal to supply electricity to the nearby street lights [23]. It can be used in places where water quantity is scarce. In such scenarios, water recirculation can provide the flowing water pressure, which can be further converted into electricity and stored for running portable electronic devices such as mobiles, bulbs, etc. The flowing source of water can be further be replaced by sea waves or ocean waves and even raindrops for obtaining the necessary dynamic vibration motion so that we can generate piezoelectricity via the suggested study [24-26]. Medical applications of the study are enormous as the blood flow in our veins can act as a flowing fluid source for a nanosystem device. This can help us develop bio-sensors to keep a regular check of the patient's vitals such as blood pressure, sugar level, etc. Also, MEMS systems such as nanogenerators and nanopumps can be powered by using this technique of generating piezoelectric energy from the motion of a fluid at a nano-scale [27-29]. Overall, the following study can help decrease our growing reliance over non-renewable energy sources and can supply us with an environmental-friendly and cost-effective energy source for both urban and rural regions.

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